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THE INFLUENCE OF AMBIPOLARITY ON PLASMA CONFINEMENT AND THE PERFORMANCE OF ECRIS

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ABSTRACT

Charge diffusion in an ECRIS discharge is usually characterized by non ambipolar behavior. While the ions are transported to the radial walls, electrons are lost axially from the magnetic trap. Global neutrality is maintained via compensating currents in the conducting walls of the vacuum chamber. It is assumed that this behavior reduces the ion breeding times compared to a truly ambipolar plasma. We have carried out a series of dedicated experiments in which the ambipolarity of the ECRIS plasma was influenced by inserting special metal-dielectric structures (MD layers) into the plasma chamber of the Frankfurt 14GHz ECRIS. The measurements demonstrate the positive influence on the source performance when the ECR plasma is changed towards more ambipolar behavior.

INTRODUCTION

A very efficient method to improve the extracted currents from an Electron Cyclotron Resonance Ion Source (ECRIS) is to insert a specially processed metal-dielectric structure into the plasma chamber. Having a dielectric layer formed on the inner surface of an aluminum cylinder (MD-liner) which covers essentially the radial walls of the plasma chamber leads to an increase of the very high charge states of more than one order of magnitude [1]. The physics behind this effect is still not clear. The cylinder, which, in the presence of a sufficiently strong electric field across the very thin dielectric layer is a strong emitter of electrons into the plasma, is at the same time a perfect insulator for currents from the plasma to the plasma chamber walls. In this manner the cylinder works like a regenerative electron donor to the plasma on one hand, while it serves as a blocker for compensating wall currents on the other hand. Both, the enhancement of the plasma density as well as the increase of the ion life times (trapping times) have experimentally been observed [2], when a MD-liner was installed in the source.

In a dedicated study we have also demonstrated that the use of a MD-structure just covering the extraction electrode of the ECRIS (MD-electrode) already leads to a significant improvement, which, in contrast to the MD-liner doesn't show significant increase of the plasma density [3]. The effect observed with the MD-electrode therefore indicates that the second of the above mechanisms plays now an essential role: the change of the ambipolar nature of the plasma by cutting very effectively the flux lines for the compensating wall currents.

In this article, we report on experiments at the Frankfurt 14GHz ECRIS, where we have positioned MD-structures at different exposed positions inside the plasma chamber to further investigate the influence of a partial restoration of ambipolarity onto the source performance. For the study reported here, charge state distributions (CSD) of magnetically analyzed argon ion beams for different set-ups are presented.

EXPERIMENTS

The experiments were carried out at the Frankfurt 14 GHz ECRIS. The source was operated with pure argon as working gas. Typical values of the vacuum during operation were in the range of 10^{-7} mbar inside the source and distinctly better in the extraction beam line. The standard mode of operation of the source, i.e. a stainless steel plasma chamber with a stainless steel biased disk is considered as a reference for the experiment reported here, where the biased disk, the extraction electrode, and the radial plasma chamber walls of the source were subsequently equipped with specially processed metal–dielectric structures (denoted in the following as MD-disk, MD-electrode and MD-liner respectively).

The magnetic system of the Frankfurt ECRIS has recently been modified to close magnetic trap holes at the extraction side that formerly led to significant plasma electron losses. Due to this change, the plasma is now much better confined, so that high charge states are generated already at comparatively lower microwave power than in older experiments (700 W instead of 1000 W). CSD spectra, optimized for the production and transport of the Ar^{12+} charge state, were measured in the Faraday cup after magnetic analysis. The measurements reported here were performed at a microwave power of 600 W.

RESULTS AND COMMENTS

It has been suggested that a completely ambipolar source (no compensating wall currents) should basically be the best configuration to create highly charged ions [4]. On the other hand it is also well known, that plasma surface interactions are essential to generate sufficient flux of cold electrons from the walls into the plasma to compensate for the plasma losses. Therefore completely blocking all fluxes, e.g. by a perfectly insulating ceramic tube may be a bad choice and has not been successful so far. However, an insulating MD-structure with its special property of emitting high fluxes of secondary electrons under bombardment by charged particles is very well suited for the study of the influence of the so called Simon currents.

In a first experiment a MD disk was mounted on the injection side of the source, substituting the conventional biased disk. To be noted that a bias applied on this MD disk has no effect on the extracted beam. In figure 1 charge state distributions (CSD) for the standard biased disk with and without voltage are presented in comparison with the CSD of the MD-disk. Comparing the CSD for the standard disk with and without voltage, a clear increase of the ionic current extracted for every charge state by roughly an overall factor of 2-3 is observed when the disk bias is optimized for the extraction of ions. This well known "disk effect" is normally explained in terms of improvements of the extraction conditions by locally changing the plasma potential barrier. The slopes of the two spectra look very much alike, supporting the assumption that no further changes of the plasma parameters are connected to this effect. In contrast to this, the MD-disk changes the shape of the charge state distribution drastically. The much flatter slope over all charge states indicates much higher relative production rates of ions than in the case of the standard disk. In particular, the enhancement at high charge states demands much larger ion dwell times in the plasma for the step by step ionization and hence a much better ion confinement. Since all rates are related, also the low charge state production is enhanced by the better confinement. Therefore the MD-disk CSD`s are much closer to the equilibrium charge state distribution of a plasma without extraction than the CSD for the standard disk, where the ion dwell times in the plasma are reduced by compensating wall currents. These currents are responsible for the non ambipolar behavior of magnetically confined plasmas in conducting vessels [4]. We therefore conclude that the change in the shape of the CSD has to be ascribed to the (partial) "cutting" of these wall currents by the insulating MD-structure and hence to a partial restoration of ambipolarity.

Installing the MD-structure at the injection side was a safe way to separate this ambipolarity change from effects created e.g. by the high secondary electron emission usually created when an MD-structure is bombarded with charged particles. As we have demonstrated in an earlier experiment [5], this latter influence is negligible for a MD-disk. This situation changes if an MD-structure is positioned at the extraction wall of the source, since here this channel of secondary electron emission is no longer closed. Therefore, a MD-electrode should serve as both, to cut those wall currents that have their flux lines ending on this surface and to behave as a secondary electron emitter that in a regenerative way will enhance the plasma density and the ion confinement like in the case of an MD-liner. In order to test this scenario, a MD structure was mounted on the

ECRIS plasma electrode facing the plasma. The central hole of the structure was identical with the plasma electrode hole (10 mm)

In figure 2 the CSD for the MD-electrode and the MD-disk are compared. From the basically quite similar broad slopes it is obvious that the effect of the partial restoration of ambipolarity is present for the MD-electrode as well. At the same time, however, also the “secondary electron emission effect” can be seen from the fact that for the MD-electrode the low charge states are depleted while the higher charge states are enhanced. The relative ratios of both processes can no longer be separated, however, and one has to conclude, that both processes working together are responsible for the good results achieved with MD-liners [1, 2]. Also given in fig 2 is the CSD for the case when the source is additionally equipped with a normal MD-liner (150mm length, covering the radial walls of the plasma chamber). Here the shift towards highest charge states becomes very pronounced. Since MD-liner and MD-electrode cover more than 80% of the plasma chamber walls this situation comes closest to the case of really ambipolar plasma having the highest possible confinement and electron temperature for a given pressure and microwave power. All results of the experiments are summarized in tab. 1, where the relative shifts in mean charge state for the different scenarios are given for two windows of analysis. The improvements by the different set ups are evident.

It was also a goal for this experiment to look for better methods of installing a MD-structure inside an ECRIS, since the necessary good thermal contact and long conditioning times of a large area MD-liner are not always acceptable. For this reason the MD-electrode, used in this experiment, was already equipped with a collar of 10mm height, which worked essentially like a very short MD-liner. Further evidence was found in an experiment carried out at the 18GHz PHOENIX ECRIS at LPSC, Grenoble, where a MD-electrode (without additional collar) was mounted on top of the extraction electrode. The CSD for the standard operation and for MD-electrode are displayed in Fig 3. The source was run at a microwave power of 500W; the beam transport was optimized for Ar^{8+}. The improvement by using the MD-electrode is obvious and, although at a much higher level of performance, it is also obvious that the relative behavior is analogous to that observed in the Frankfurt ECRIS. This demonstrates that the effect is universal and that already a small structure may cause significant improvements also in a very modern state of the art ECRIS. It is therefore a way to overcome the problem with heat contact and conditioning.

The combination MD-liner + MD-extraction electrode was installed in the plasma chamber of the Frankfurt ECRIS for several months. No deterioration of the good performance of operation has been found so far.

References

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Table captions:

Table 1: Evolution of the average charge states

Figure captions:

Figure 1:

Charge state distributions (CSD) for the standard (stainless steel) biased disk at U_{bias}=0V (open squares), for the optimized bias U_{bias}=300V(open triangles) and CSD for the Source equipped with a MD-disk (full squares), optimized for the transport of Ar^{12+}.

Figure 2:

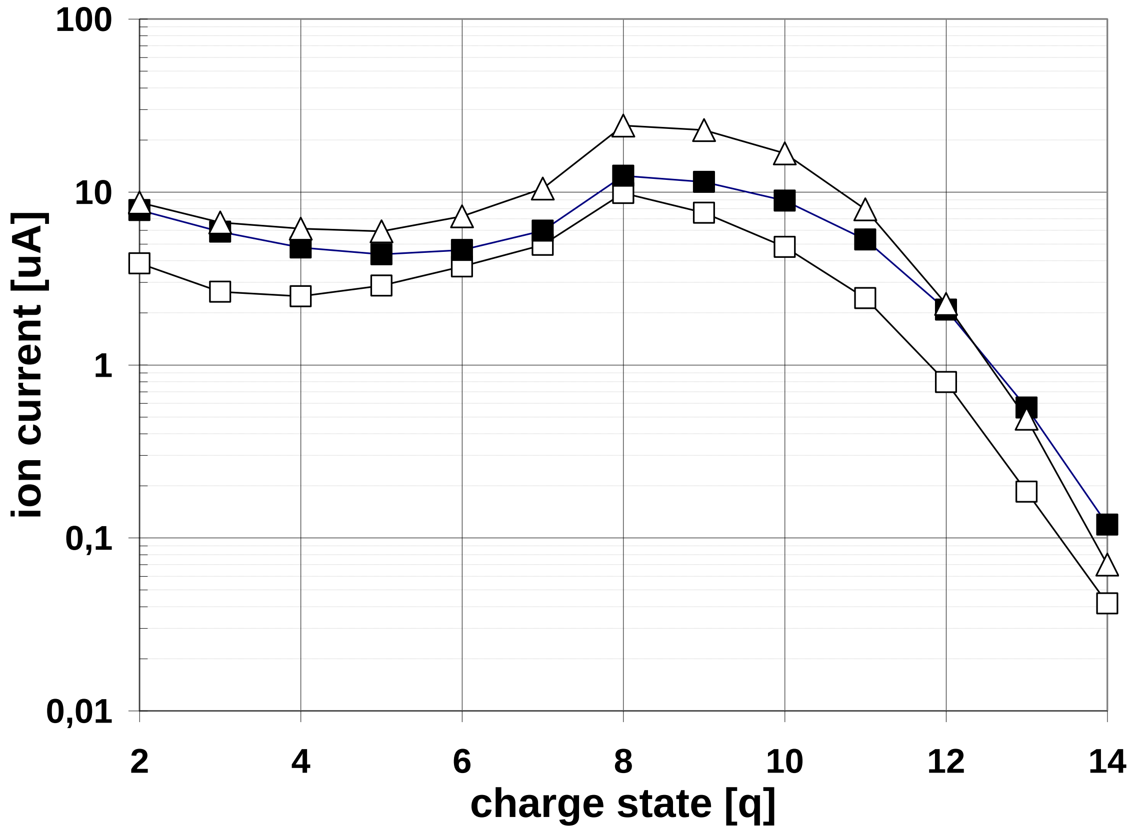
Charge state distributions for three different MD-structure configurations: MD-electrode (open circles), MD-disk (full squares) and MD-liner + MD-electrode, optimized for the transport of Ar^{12+}.

Figure 3:

Charge state distributions measured at the 18GHz PHOENIX source at LPSC, Grenoble for the standard source (open circles) and for the source equipped with a MD-electrode (full circles)

Average charge state	**Standard disk**	**MD-injection disk**	**MD-extraction electrode**	**MD-liner + MD-extraction electrode**
q(8-16)	9.012	9.310	9.145	9.784
q(11-16)	11.320	11.442	11.416	11.548

Table 1: Evolution of the average charge states



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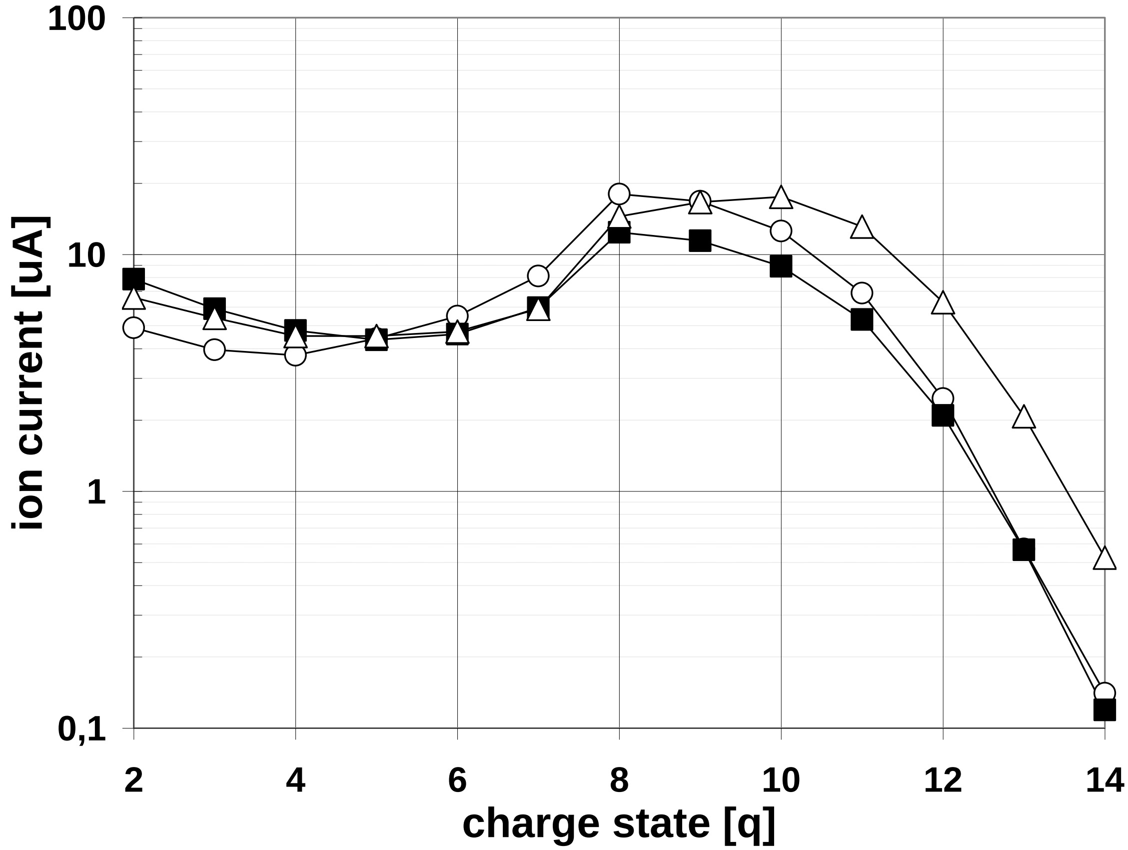

Figure 2.

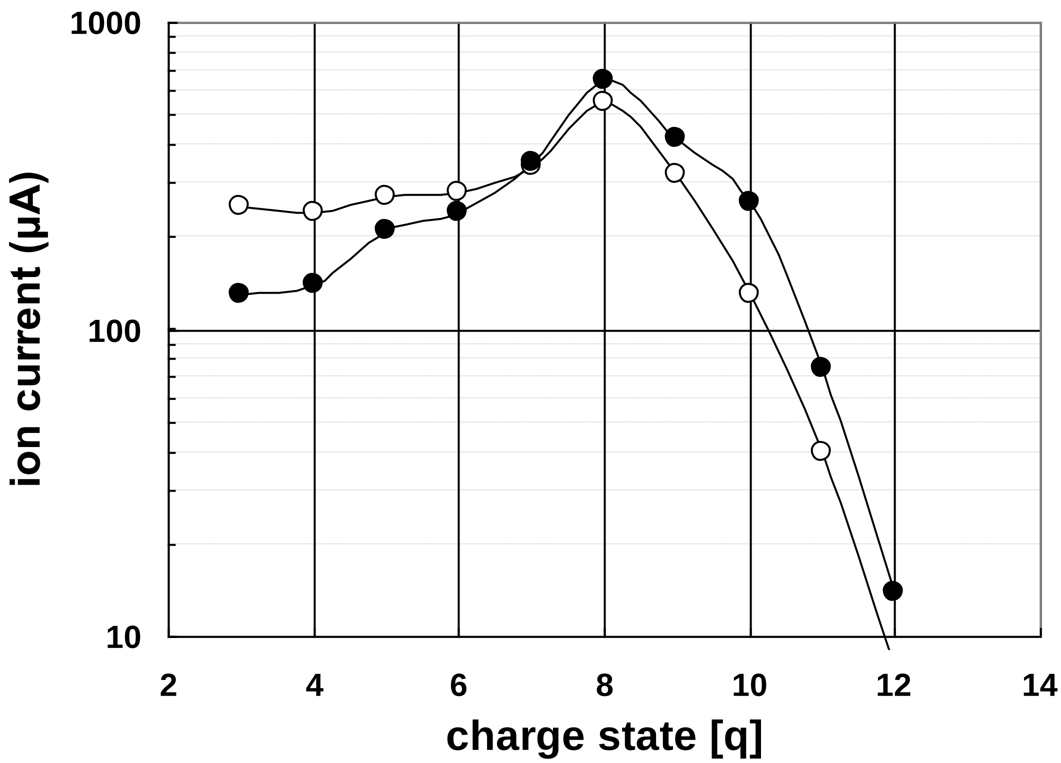

Figure 3